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Nanofabrication Technology for Production of Quantum Nano-electronic Devices Integrating Niobium Electrodes and Optically Transparent Gates

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EXECUTIVE SUMMARY

This technical report demonstrates nanofabrication technology for Niobium heterostructures and nanoscale quantum devices suitable for implementation in novel qubit/quantum memory. In particular electron beam lithography and atomic layer deposition are used. These processes integrate layouts suitable for high frequency microwave/RF excitation of the qubits/quantum memory as well as optically transparent nanowire gates in the area of the tunnel junction to enable combined spectroscopy and transport measurements while tuning the energy band at the tunnel junction. These devices are suitable for characterization in a cryo-magneto-optical probe station to access the superconducting regime of operation and that could be used for control and sending of qubit/quantum memory states to remote locations.

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1. INTRODUCTION

Niobium metal is used in the implantation of a variety of superconducting quantum devices. However, the technology is typically limited to use in conventional Josephson junctions based on Nb-AlOx-Nb produced entirely by sputtering. In addition, the devices are most commonly in a vertical stack covered by niobium metal, making it physically limited to access the embedded films that could comprise insulators, semiconductor, or hybrids with ions.

There is a need for improvement in the design as well as integration of functional materials for use in devices such as qubits as well as ion embedded devices for quantum memory. Also, implementation of large scale computers requires nanofabrication technologies. Sending qubits states and implementing quantum networks requires an optical interface. In this work, we present nanofabrication processes and results that address these needs and challenges. The use of these devices in the above mentioned applications will be presented in a later report.

2. EXPERIMENT

2.1 DESIGN CONSIDERATIONS

Certain applications require the ability to gate the active region and use multi-terminal configurations. The previously designed heterostructures with the top Niobium electrode have a problem with as their optical gating limits access to the active junction region. We created a layout for the construction of lateral devices where tunneling can occur. We came up with a modified layout based on microwave integrated circuit ground-signal-ground layouts used for radio frequency (RF) electronics. We modified the active region to act as a tunneling junction. As for the tunneling junction, we produce structures that have a “closed” but constricted gap at or near the coherence length for Niobium to behave as a weak-link and where functional materials can readily be integrated in the tunneling region.

2.2 NANOFABRICATION OF NIOBIUM ELECTRODES

Starting material is 4-in silicon wafers with 300 nm of thermal SiO2. One hundred nm of Niobium is DC sputtered in the presence of argon at 200 watts. The samples are pattered and developed with ma-N 2405 electron beam negative resist and exposure with a Vistec Electron Beam lithography system. Dose tests measured optimal exposure conditions (pending input from University of California San Diego (UCSD)/Nano3). After dose testing, resist development and bake SF6 etching is done to define the lateral Niobium nanoscale patterns followed by two cycles of O2 plasma etching and SF6 etching to clean the surface. Layouts are developed in a complete microwave layout as shown in Figure 1a where the device is arranged in a ground-signal-ground configuration. The layout was made where the gap region of the active tunneling junction was varied from closed configurations in Figure 1b to opens in Figure 1c and 1d with varying gap length. The open junctions are formed specifically to enable deposition of novel functional materials in the tunneling gap region, such as a S-B-I-B-S structure previously examined or other structures as desired by the application.

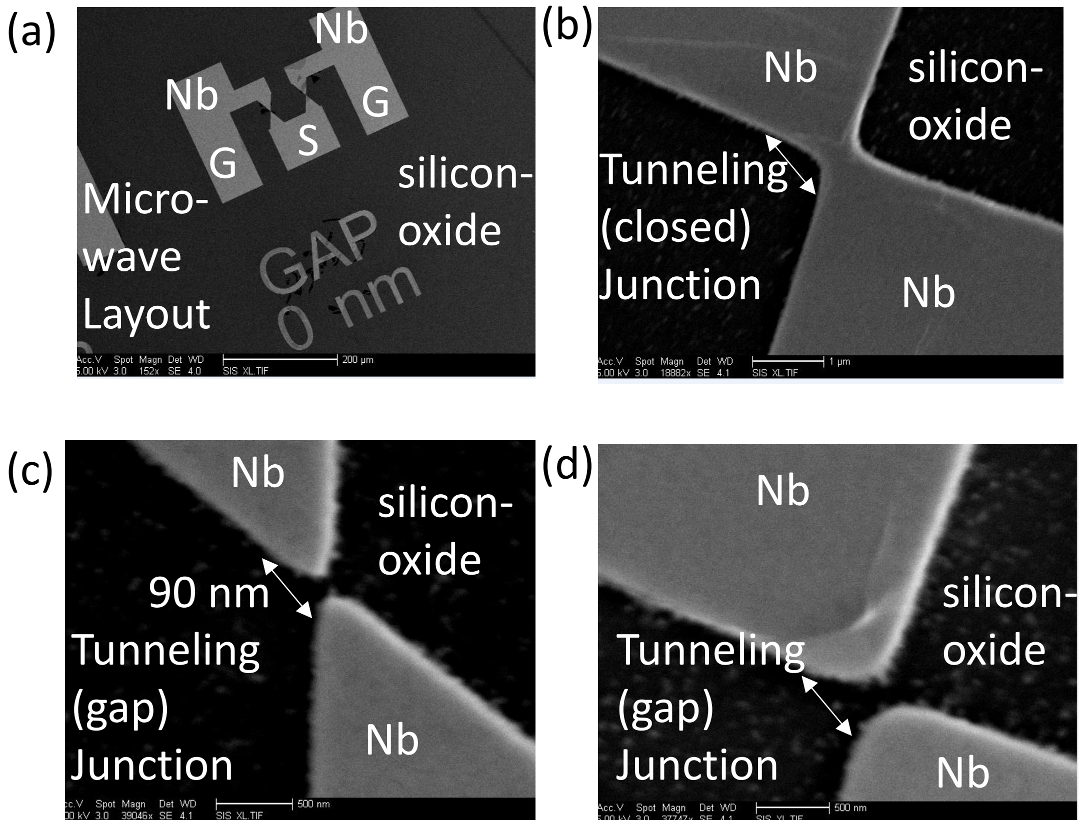

Figure 1. High resolution scanning electron microscopy of a full device in microwave ground-signal-ground layout (a), the case of a closed tunneling junction region (b), open (c), and open tunneling junction (d).

2.3 NANOFABRICATION OF ALIGNED OPTICALLY TRANSPARENT GATES

After patterning of the niobium, a second exposure was completed to define indium-tin-oxide gate electrodes (ITO) by a lift-off process. The aligned exposure was assisted by the formation of alignment markers during the previous lithography step. Polymethyl methacrylate (PMMA) positive resist is used as the resist and dose tests were completed to optimize the exposure conditions. After the resist development and bake, a 2-second descum oxygen-plasma exposure is performed followed by RF sputtering at 100 watts in argon of indium-tin-oxide (ITO) and subsequent lift-off in acetone using standard lift-off procedures. Figure 2shows completed structures with nanowire gate widths down to sub-100 nm dimensions that are well positioned over the tunneling junction.

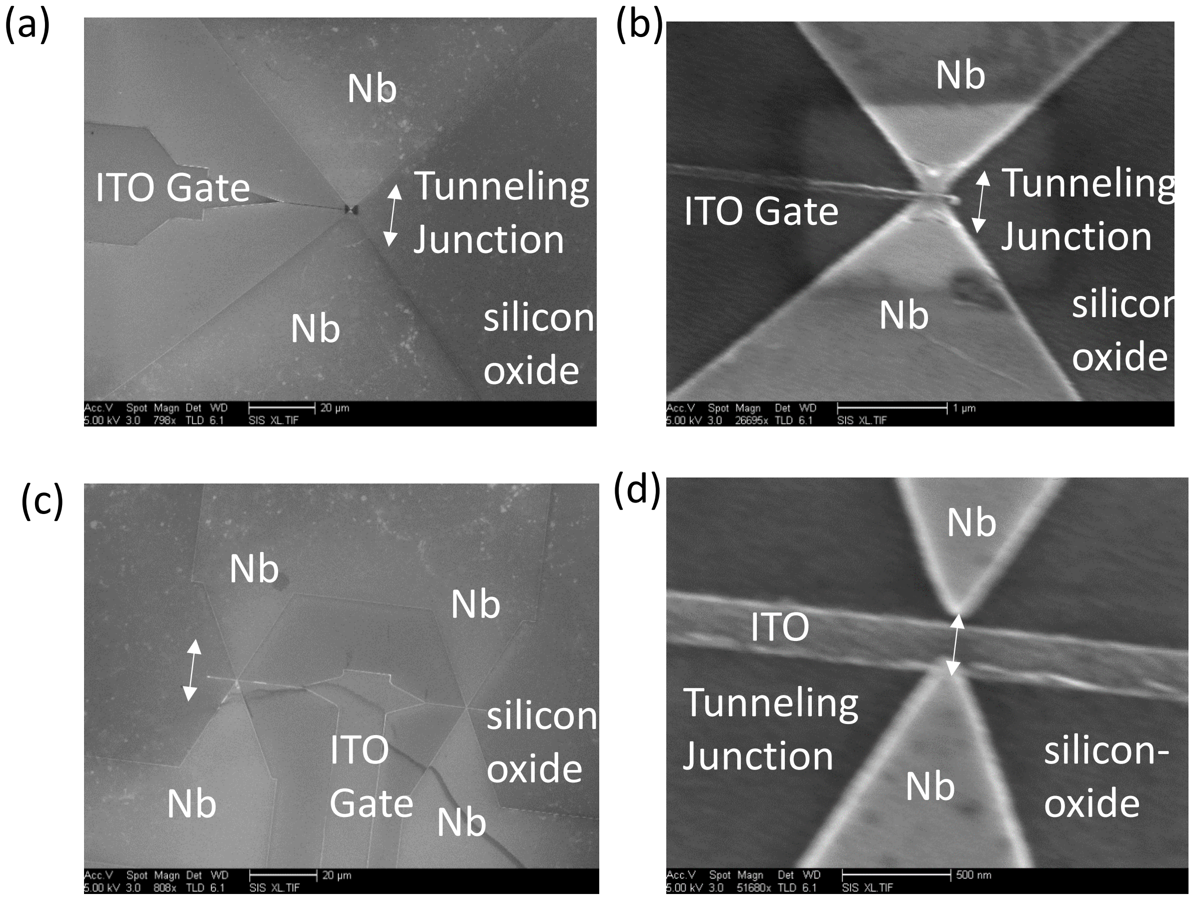

Figure 2. High resolution scanning electron microscope images of gate electrode in the vicinity of the tunneling junction (a), close ups of a gate electrode over a closed gap (b), gate electrode over an open gap (c) and gate electrode in an open gap (d).

3. SUMMARY

We demonstrate nanoscale processing of niobium devices in lateral configurations suitable for operation in the qubit/quantum memory regime of operation with integration of a microwave/RF layout and optically transparent nanowire gate electrodes. The process targets nanoscale feature size and provides flexibility for integration of novel materials in the tunneling junction region.

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14. ABSTRACT

This technical report demonstrates nanofabrication technology for Niobium heterostructures and nanoscale quantum devices suitable for implementation in novel qubit/quantum memory. In particular electron beam lithography and atomic layer deposition are used. These processes integrate layouts suitable for high frequency microwave/RF excitation of the qubits/quantum memory as well as optically transparent gates in the area of the tunnel junction to enable combined spectroscopy and transport measurements while tuning the energy band at the tunnel junction. These devices are suitable for characterization in a cryo-magneto-optical probe station to access the superconducting regime of operation and that could be used for control and sending of qubit/quantum memory states to remote locations.

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